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LF AND MF PROPAGATION:
an approximate formula for estimating sea gain

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LF AND MF PROPAGATION: AN APPROXIMATE FORMULA FOR ESTIMATING SEA GAIN

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Summary

The strength of waves propagated via the ionosphere at l.f. or m.f. may be increased if either path terminal is situated near the sea. This increase, which is known as sea gain, depends both on the distance of the terminal from the coast and on the extent of the sea beyond the coastline. An approximate formula is derived for estimating sea gain for all geographical situations which are likely to be encountered.

Issued under the authority of

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Head of Research Department

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P. Knight, M.A., Ph.D., M.I.E.E.

1. Introduction

The sky-wave field-strength prediction method for l.f. and m.f. described in the Annex to CCIR Report 575, which was adopted by Part I of the Regional Administrative Broadcasting Conference for use in I.T.U. Region 1 and in part of Region 3, contains an approximate formula for estimating sea gain. The description which accompanies this formula is rather unsatisfactory because it does not say how far the sea must extend in the direction of propagation; sea gain will, of course, be considerably reduced if the sea is of very limited extent. The effect which the finite width of a sea channel or inlet has on sea gain has now been studied and is discussed here; for convenience the term 'channel' will be used below.

The derivation of the present CCIR formula, which takes account of the distance of a terminal from the coast, is described here in Sections 2 and 3. Section 4 considers how the finite width of a channel influences sea gain and states an approximate formula which applies when a terminal is situated on the edge of a channel. The two formulae are combined in Section 5, to enable sea gain to be estimated for a terminal which is some distance inland from the edge of a channel. Appendix 2 indicates how the combined formula could be incorporated in CCIR Report 575.

2. Sea gain for a terminal on the coast

The sea gain which occurs when an inland terminal is replaced by a terminal on the coast depends on the conductivity at the inland site; the poorer the conductivity the greater the sea gain. Sea gain is greatest at low radiation angles.

Curves which enable sea gain to be estimated when a terminal well inland is replaced by a terminal on the coast, assuming the sea to be of unlimited extent, are contained in Fig. 1 of CCIR Report 401-2. These curves take diffraction around the curvature of the Earth into account and extend to negative radiation angles.

Sea gain in greatest at low radiation angles and therefore increases as the path length increases, reaching a maximum near the limit of the 1-hop propagation mode, i.e. when the path length is about 2000 km. Beyond 2000 km the 1-hop mode is replaced by the higher-angle 2-hop mode and the sea gain decreases rapidly. It rises again to a second maximum at about 4000 km, the limit of the 2-hop mode.

The effective sea gain for any path length depends on the sum of all the modes which contribute significantly to the received signal. Effective sea gains, for North-South and East-West paths of various lengths, have been calculated

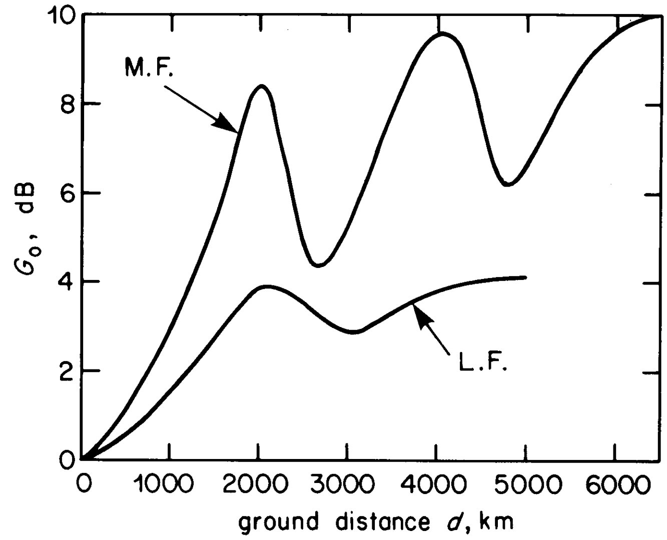
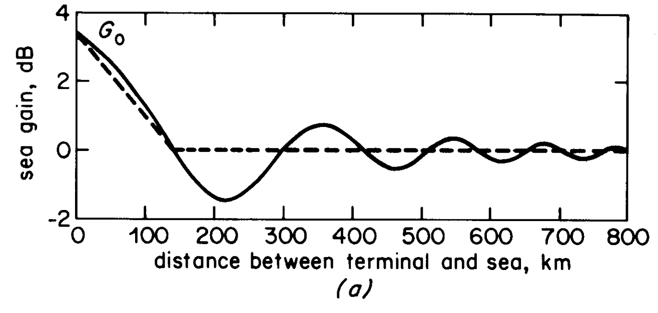


Fig. 1 - Sea gain (G_0) for a single terminal on the coast
Ground conductivity 10 mS/m



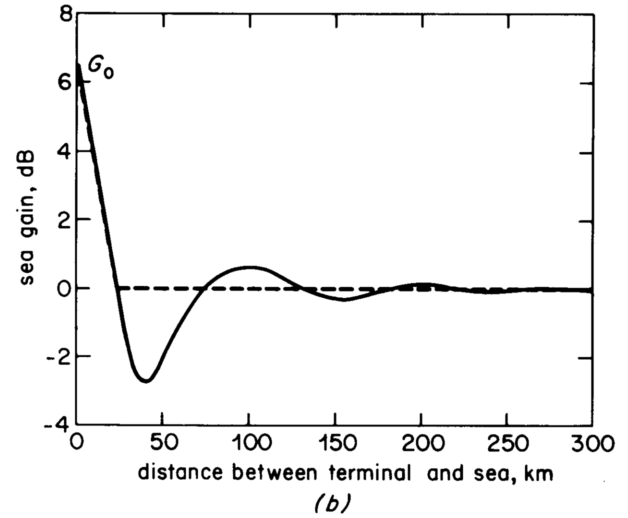


Fig. 2 - Sea gain for an inland terminal
(*a*) 200 kHz (*b*) 1 MHz
——— Computed curve – – – – – Linear approximation
Radiation angle 3° Ground conductivity 10 mS/m

by the wave-hop method[1] for 0·5 and 1·5 MHz, assuming the ground conductivity at the inland site to be 10 mS/m. As the difference between sea-gain curves drawn for the two frequencies was found to be insufficient to justify the use of more than one curve at m.f., an intermediate curve was drawn and is reproduced in Fig. 1. A modified form of the wave-hop method was also used to calculate effective sea gain at 200 kHz, and the resulting curve is also shown in Fig. 1. Both of these curves have been adopted by the CCIR and are included in Report 575. Further calculations showed that the sea gain is doubled if both terminals are on the coast.

3. Sea gain for an inland terminal

The sea gain shown in Fig. 1 decreases if the terminal is situated some distance from the coast. The effect of moving the terminal inland has been studied both theoretically (assuming the Earth to be flat) and experimentally.[2,3] Earth curvature, which has a significant effect at l.f. and at the lower frequencies in the m.f. band, has since been taken into account and Fig. 2 shows typical results.[4]

For frequency planning it is not feasible to take account of all the detailed variations shown in Fig. 2. In the method adopted by the CCIR, the reduction in sea gain is assumed to be linear up to the distance at which it first falls to zero and to be zero for all greater distances. This approximation is represented by the broken lines of Fig. 2.

Fig. 2 applies to waves propagating at 3° to the

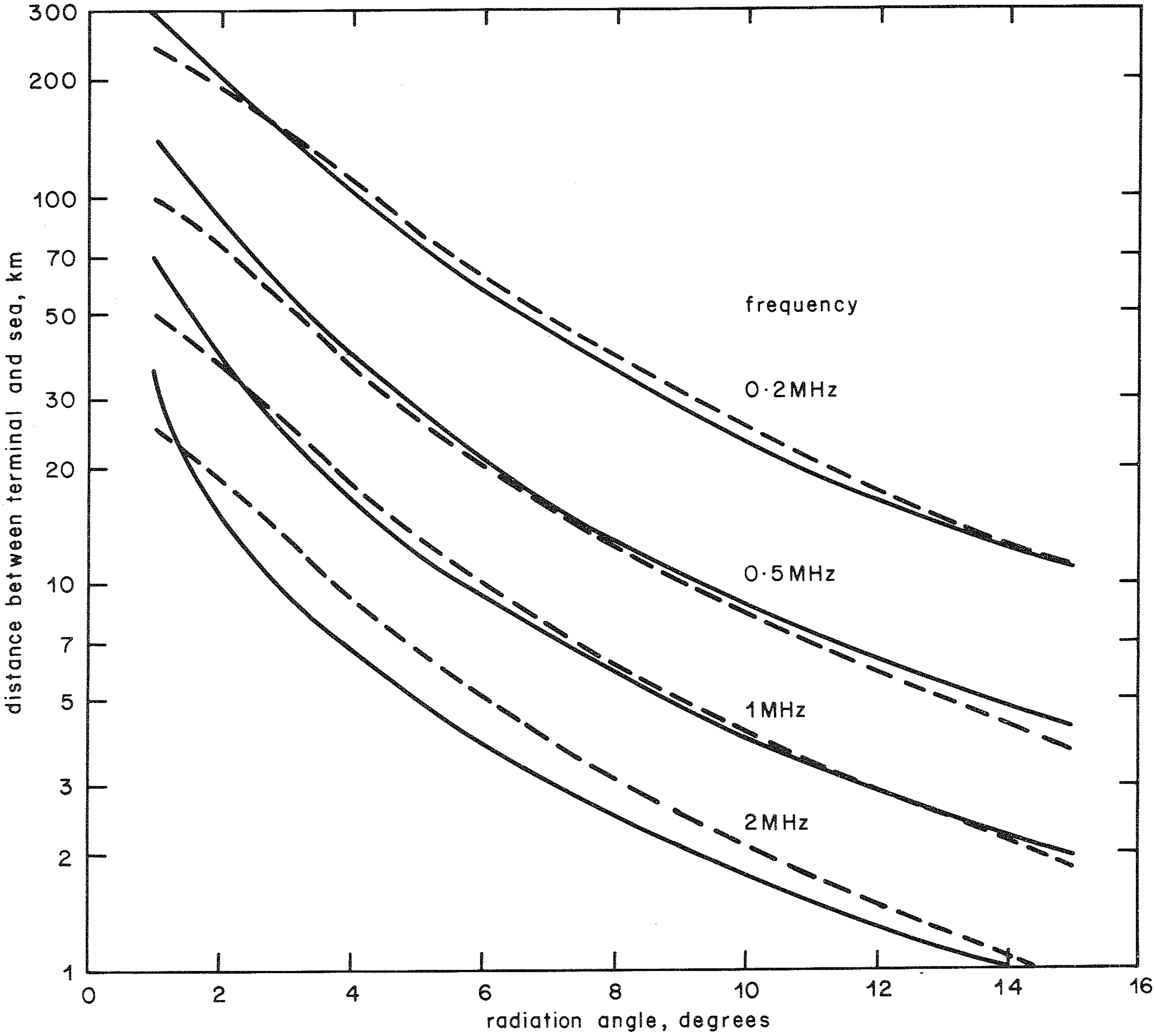


Fig. 3 - Distance from coast at which sea gain falls to zero

——— Computed distance — — — Distance given by semi-empirical formula

Ground conductivity 10 mS/m

horizontal. Fig. 3 shows that the distance at which sea gain falls to zero depends to a great extent on the radiation angle, which in turn depends on the path length. To avoid the need to determine the radiation angle as an intermediate step, the distance referred to above has been expressed in terms of the sea gain for a coastal site (G_0) given by Fig. 1, since G_0 also depends on radiation angle and path length. Fig. 3 also shows that the distance in km at which sea gain first falls to zero may be expressed with reasonable accuracy, when G_0 is given by Fig. 1, by the following semi-empirical formula, discussed in Appendix 1:

$$r_1 = 10^3 \frac{G_0^{\,2}}{Q_1 f} \qquad (1)$$

where Q_1 is a constant and f is the frequency in kHz. The linear sea gain approximation referred to above is then given by:

$$G_s = G_0 \left(1 - \frac{s_1}{r_1}\right) \qquad s_1 < r_1 \qquad (2)$$

$$G_s = 0 \qquad s_1 > r_1 \qquad (3)$$

where all distances are measured along the great-circle path.

Equation (2) is the same as that adopted by the CCIR (see Equation (3) of the Annex of Report 575). The values of Q_1 given in Report 575 are 0·44 and 1·75 for l.f. and m.f. respectively. More detailed calculations made recently, however, lead to values of 0·30 (l.f.) and 1·40 (m.f.); the curves shown in Fig. 3 were calculated with these constants.

4. Sea gain for a terminal on the edge of a channel

The sea beyond the coastline has been assumed so far to be of unlimited extent. As this is not necessarily the case, the effect of a channel of finite width has been studied. In this section the terminal is assumed to be on the coast.

The theory contained in Reference 2 has been modified to take Earth curvature into account and Fig. 4 shows typical computed curves.[4]

As in Section 3 it is proposed that the increase in sea gain should be assumed to be linear until it attains the value (G_0) corresponding to sea of unlimited extent, and equal to G_0 if the width of the channel is greater. This approximation is represented by the broken lines of Fig. 4. Computations show that the distance r_2 (km) at which the sea gain first reaches G_0 may be expressed in the terms of the values of G_0 given in Fig. 1 by the following semi-empirical formula

$$r_2 = 10^3 \frac{G_0^{\,2}}{Q_2 f} \qquad (4)$$

where Q_2 is a further constant, equal to 0·25 at l.f. and 1·20 at m.f. The variation of sea gain with the width of the channel is then given by:

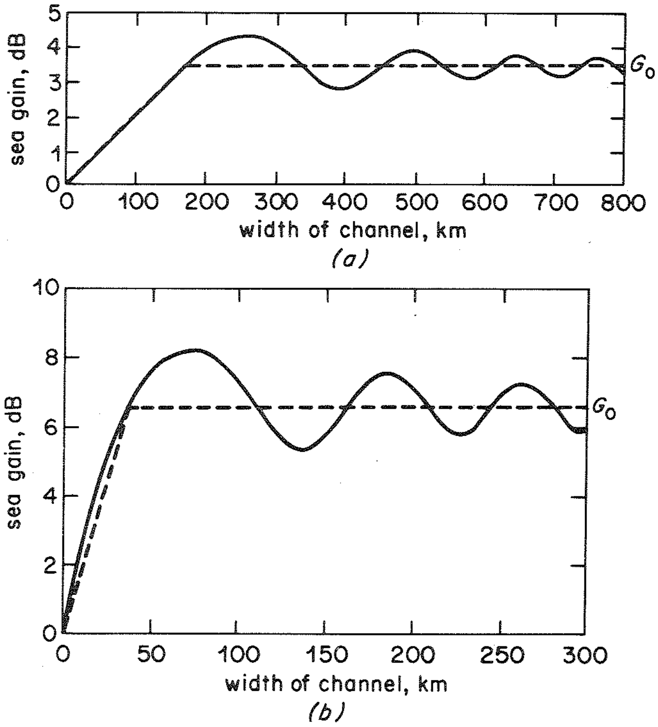


Fig. 4 - Sea gain for a terminal on the edge of a sea channel

(*a*) 200 kHz (*b*) 1 MHz

——— Computed curve – – – – – Linear approximation

Radiation angle 3° Ground conductivity 10 mS/m

$$G_s = \frac{s_2 G_0}{r_2} \qquad s_2 < r_2 \qquad (5)$$

$$G_s = G_0 \qquad s_2 < r_2 \qquad (6)$$

It has been assumed in this section that the land on the far side of the channel is of unlimited extent. If this is not the case (e.g. if the land on the far side is a peninsula or island) it is proposed that G_s should be calculated according to the following rules:

(1) If more than half the distance between s_2 and r_2 is occupied by land, $G_s = s_2 G_0 / r_2$.

(2) If less than half the distance between s_2 and r_2 is occupied by land, $G_s = G_0$.

5. Sea gain for a terminal near a channel

In Section 4 the terminal was assumed to be on the edge of a channel. It may, however, be some distance inland.

This situation is considered theoretically in Reference 2 but the solution is extremely complex and is not convenient for computation. Reference 2 does, however, contain a few computed curves which can be used to justify the very simple method proposed below.

Equations (2) and (5) may both be written in the form:

$$G_s = G_0 - \Delta \qquad (7)$$

where Δ is a correction which describes how sea gain is reduced, either by the distance of the terminal from the sea or by the finite width of a channel. Here it is proposed that the two corrections be applied simultaneously when the terminal is both inland and near a channel. The resulting expression for G_s is then:

$$G_s = \left(\frac{s_2}{r_2} - \frac{s_1}{r_1}\right) G_0 \qquad (8)$$

where all distances are measured from the terminal along the great-circle path. The range of validity of Equation (8) is governed by the conditions outlined in Sections 3 and 4 and stated more precisely in Appendix 2, which is a draft revision of the appropriate section of CCIR Report 575.

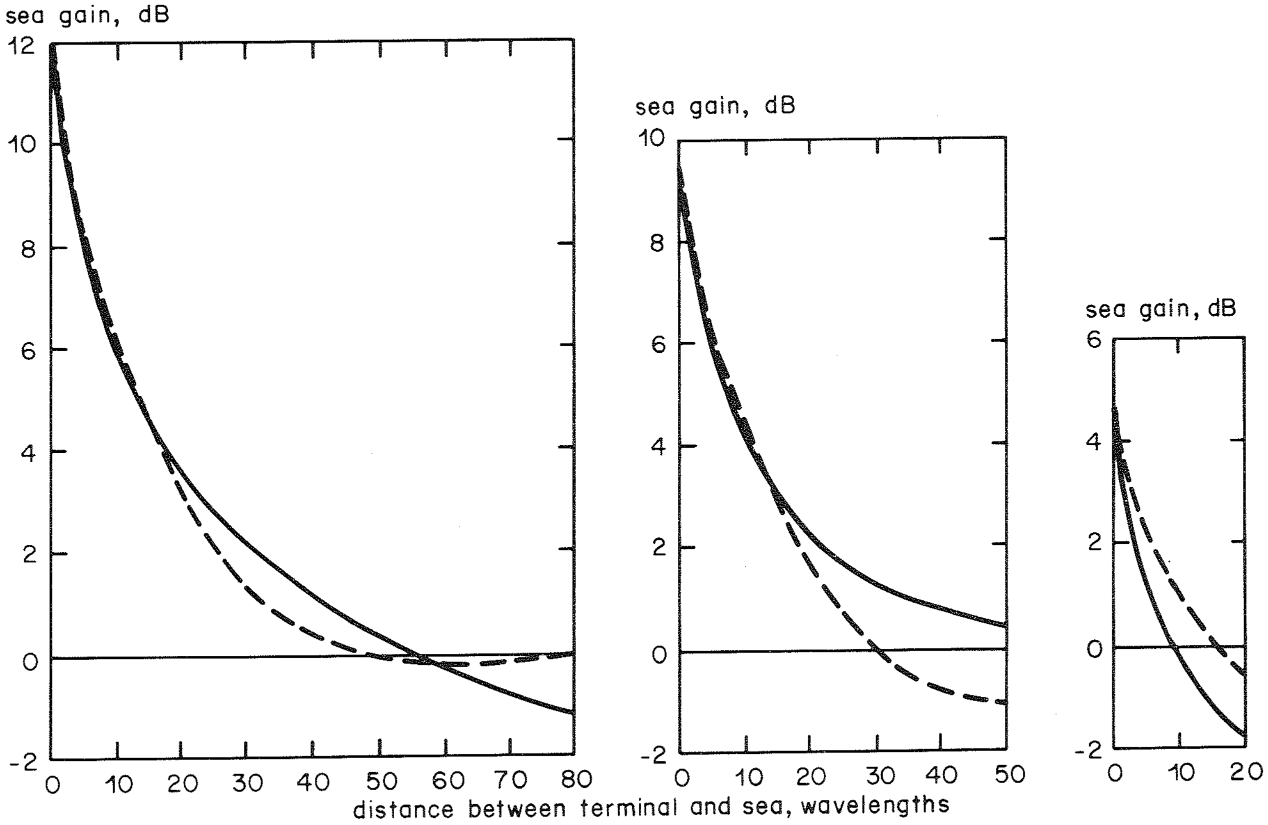
Fig. 5 shows how this procedure was justified. The full-line curves are derived from Fig. 5 of Reference 2 and show how sea gain varies as a terminal moves inland from the edge of a channel of given width. The broken lines were drawn by subtracting the two separate corrections, derived from Figs. 3 and 6 of Reference 2, from G_0. The agreement is not exact but the discrepancies are least where the sea gain in greatest.

6. Discussion

The approximate sea-gain formula proposed in Section 5 and specified in detail in Appendix 2 is known to agree reasonably well with the more exact formulae of References 2 and 4 if (a) the terminal is inland and the sea is of unlimited extent or (b) if the terminal is on the edge of a channel. It is thought to be reasonably accurate if the terminal is situated both inland and near a channel. It is important to note that the formula applies only when the ground conductivity is 10 mS/m (the value adopted by the CCIR) and G_0 has the values given in Fig. 1.

The conditions for the use of this formula, specified in Appendix 2, should anticipate all geographical situations which can arise and should avoid ambiguity when coastline data are being specified for use in a computer.

As a guide for the preparation of data, Fig. 6 shows the distances (r_1 and r_2) to which coastline data should be specified. These distances were calculated from Equations (1) and (4) with the appropriate values of G_0, Q_1 and Q_2.



(a) (b) (c)

Fig. 5 - Sea gain for a terminal near a sea channel

Width of channel (*a*) 64λ (*b*) 32λ (*c*) 6·4λ

——— Curves derived from Fig. 5 of Reference 2 — — — — Curves calculated by approximate method

Radiation angle 4° Ground conductivity 10 mS/m Frequency 10 MHz

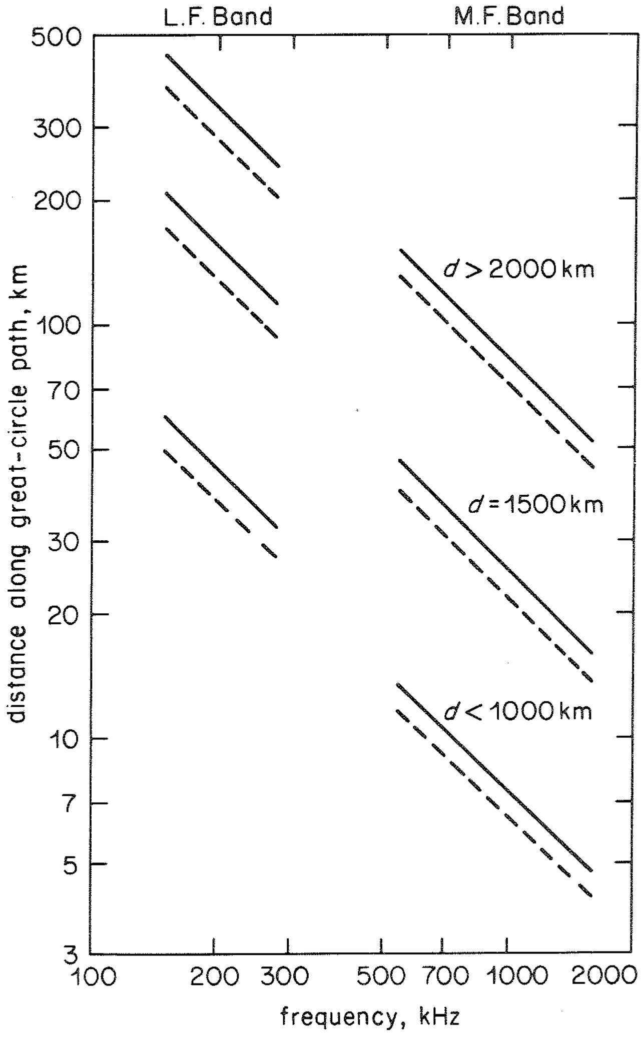


Fig. 6 - Distances to which coastline data should be specified

– – – – – – Distance between terminal and sea (r_1)

——————— Distance from terminal to next land (r_2)

d = path length

The small differences between r_1 and r_2 suggest that little error would arise if the formulae were simplified still further by making r_1 and r_2 equal. If this were done, Equation (8) would simplify to:

$$G_s = (s_2 - s_1)\frac{G_o}{r} \qquad (9)$$

where

$$r = 10^3\,\frac{G_o^{\,2}}{Qf} \qquad (10)$$

Suitable values of Q would be 0·28 (l.f.) and 1·3 (m.f.).

7. References

1. KNIGHT, P. 1973. MF propagation: a wave-hop method for ionospheric field-strength prediction. BBC Engineering No. 100, pp. 22 – 33, June 1975.

2. ANDERSEN, J.B. 1962. The radiation field from a vertical dipole on an inhomogenous ground. *Electromagnetic Theory and Antennas* (edited by E.C. Jordan) pp. 1099 – 1112. Pergamon Press, Oxford, 1963.

3. KNIGHT, P. *and* THODAY, R.D.C. 1968. Influence of the ground near transmitting and receiving aerials on the strength of medium-frequency sky waves. *Proc. IEE,* **116**, pp. 911 – 919, June 1969.

4. LF and MF propagation: the effect of Earth curvature on sea gain. BBC Research Department report in preparation.

Appendix 1

Derivation of the Semi-empirical Formulae

Equation (1) is a semi-empirical formula which gives the approximate distance at which sea gain falls to zero, in terms of G_0 and the frequency, when a terminal moves inland. Equation (4) is a similar expression which gives the minimum width of channel which is required for sea gain to be equal to G_0.

Both of these distances depend on the path difference in wavelengths between waves propagating directly to or from the terminal and those propagating via the discontinuity, as shown in Fig. 7. Neglecting Earth curvature, this path difference is proportional to $fr(1 - \cos\psi)$, where f is the frequency, r the distance between the terminal and the discontinuity and ψ the radiation angle. If ψ is small the path difference is proportional to $fr\psi^2$. It follows therefore that the distance r which corresponds to a particular path difference is proportional to $1/f\psi^2$.

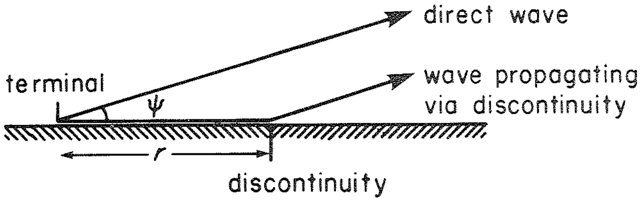


Fig. 7 - Waves propagating from a terminal

It can be shown that the product $G_0\psi$ is almost constant for the dominant propagation mode, for all distances between terminals. Consequently the distance r which corresponds to a given path difference is proportional to G_0^2/f; this is the basis of the semi-empirical formulae. The constants Q_1 and Q_2 were so chosen that the differences between distances calculated from the formulae and those computed by the method described in Reference 4 are made as small as possible, especially at the low radiation angles where sea-gain is most important. Fig. 3 shows that the semi-empirical formula for r_1 gives reasonably accurate results over a wide range of frequencies and radiation angles; the formula for r_2 gives similar results.

Appendix 2

Draft Revision of CCIR Report 575

To include the proposed sea-gain formula in CCIR texts, Section 2.3 of the Annex of Report 575 would have to be replaced by the following:

"**2.3. Sea gain**

G_s is the additional signal gain when one or both terminals is situated near the sea. G_s for a single terminal is given by:

$$G_s = \left(\frac{s_2}{r_2} - \frac{s_1}{r_1}\right) G_0 \quad \text{dB} \qquad (3)$$

where

G_0 = gain when the terminal is on the coast and the sea is unobstructed by further land.

s_1 = distance of terminal from sea, measured along great-circle path (km).

s_2 = distance of terminal from next section of land, measured along great-circle path (km).

$r_1 = 10^3\, G_0^2/Q_1 f$

$r_2 = 10^3\, G_0^2/Q_2 f$

f = frequency (kHz)

Q_1 = 0·30 in band 5 and 1·4 in band 6

Q_2 = 0·25 in band 5 and 1·2 in band 6

G_0 is given in Fig. 7 as a function of d for bands 5 and 6. In band 6, G_0 = 10 dB when $d > 6500$ km. Equation (3) applies for values of s_1 and s_2 such that $G_s > 0$. For larger values of s_1, $G_s = 0$. If $s_2 \geqslant r_2$, G_s is calculated with $s_2 = r_2$. If $s_2 < r_2$ and if more than half the distance between s_2 and a great-circle distance equal to r_2 is occupied by land, Equation (3) applies, but if less than half the distance between s_2 and r_2 is occupied by land, G_s is calculated with $s_2 = r_2$.

If both terminals are near the sea, G_s is the sum of the values of G_s for the individual terminals."

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